Integrating Laser Diode Pump Technology into Future Space Missions

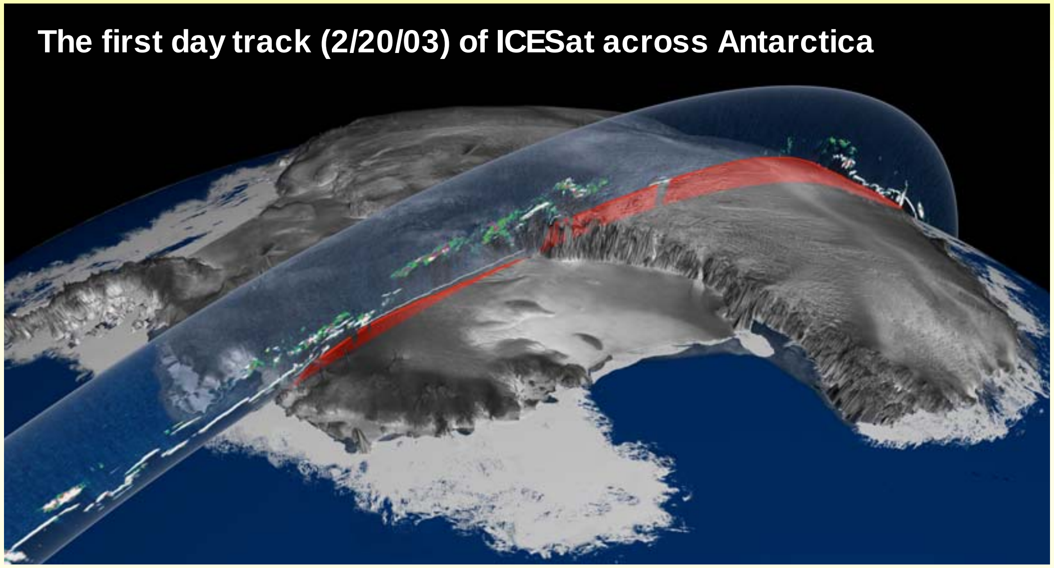
**Mark Stephen, Graham R. Allan,
Aleksey A. Vasilyev, Elisavet Troupaki,
Nasir B. Kashem,**

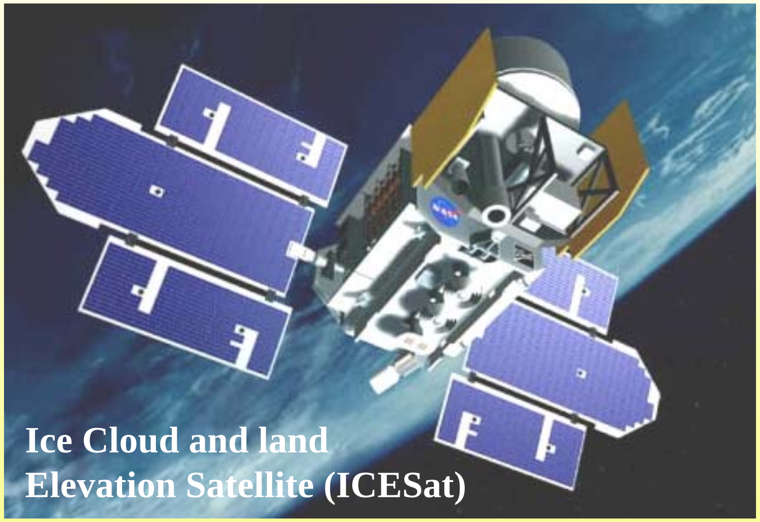
*NASA - Goddard Space Flight Center
Laser and Electro-Optics Branch*

OUTLINE

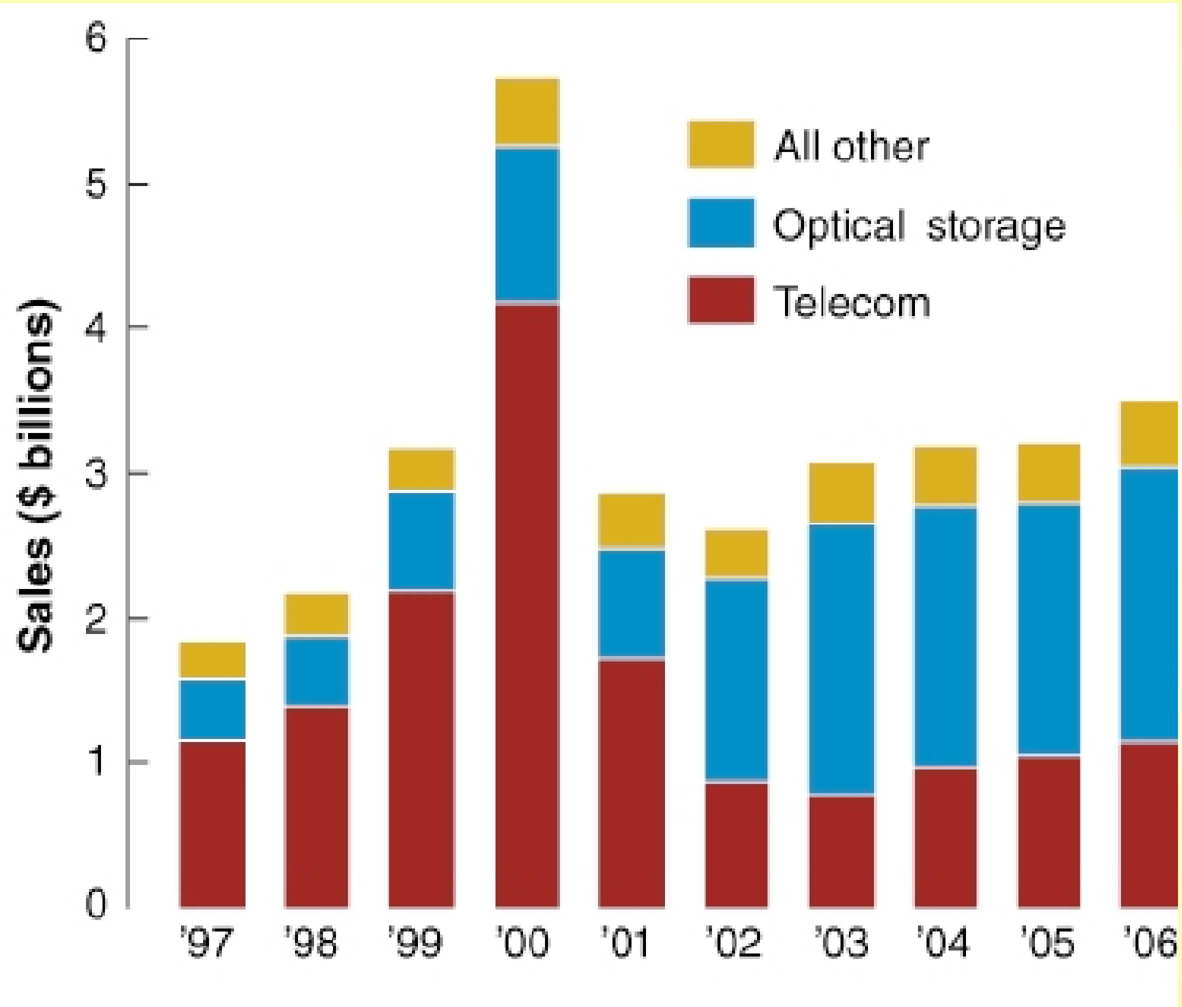
- Introduction and laser market
- Status of 980/940 nm CW and 808 nm Quasi-CW diode pumps
- Review of progress in LRRP on laser diode array qualification
- Example using LOLA instrument as a test case
- Summary and future

INTRODUCTION





Worldwide Diode-laser Market



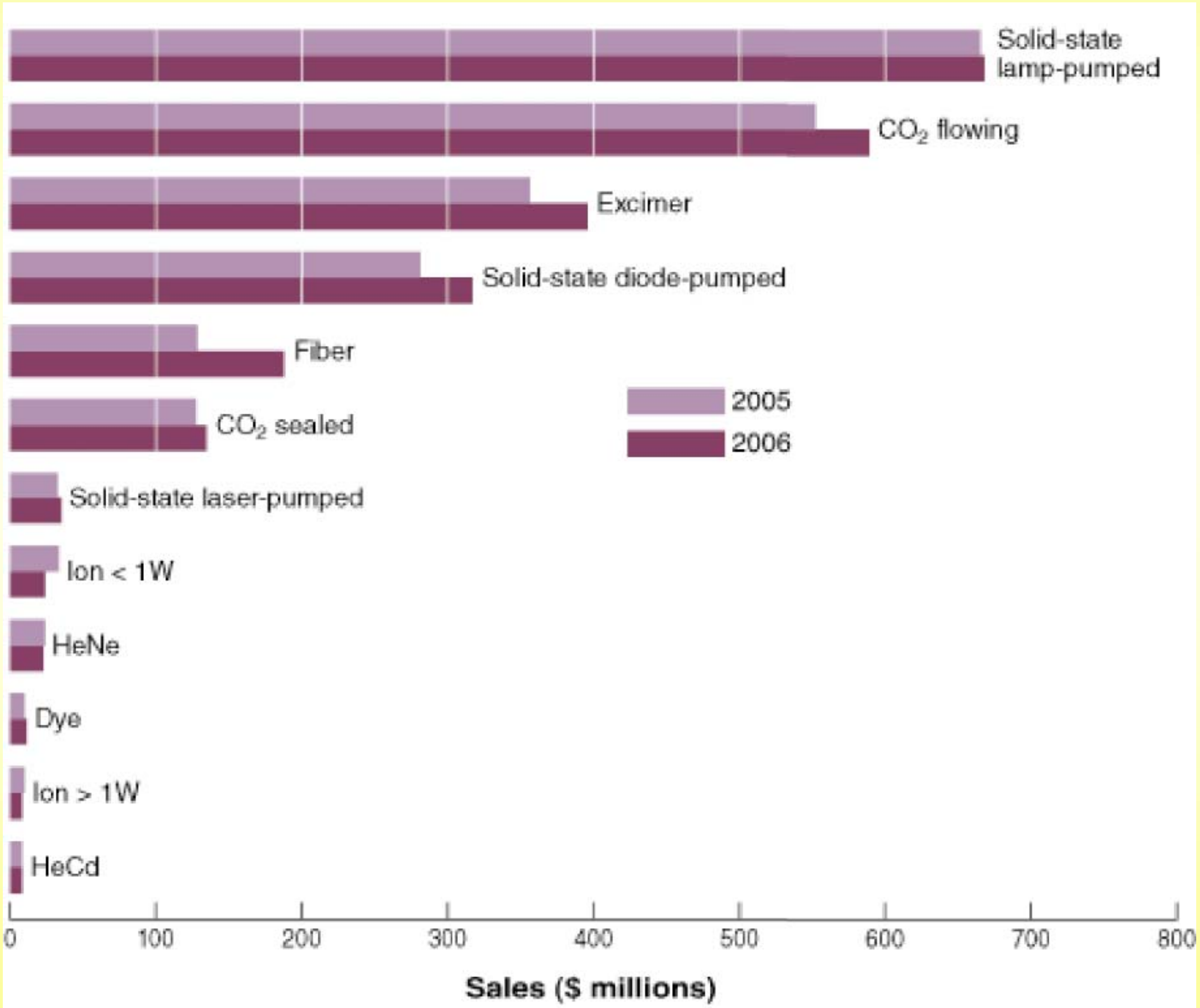
The history of the worldwide diode-laser market since 1996 shows continued growth. The market has been growing steadily since 2001.

"Laser Marketplace 2006: Market's messages are mixed," *Laser Focus World,* January, 2006

Summary of Telcordia component testing

HEADING	TEST	REFERENCE	CONDITIONS
Mechanical & Physical	Mechanical Shock	MIL-STD-883 Method 2002	Cond. B 5 times/ axis, 1,500 G, 0.5 ms
	Vibration	MIL-STD-883 Method 2007	Cond. A 20 G, 20-2,000 Hz, 4 min/ cycle, 4 cycles/ axis
	Die Shear	MIL-STD-883 Method 2019	LD/heatsink and heatsink/submount
	Wire Bond Strength	MIL-STD-883 Method 2011	Based on bond type
Endurance	Accelerated Aging	Telcordia 468 Section 5.18	85°C; rated power 5,000 hrs or 10,000 hrs
			70°C; rated power 5,000 hrs
	Temperature Cycling	Telcordia 468 Section 5.20	-40°C/+70°C 50 cycles
			-40°C/+85°C 50 cycles

Worldwide non-diode laser sales



Worldwide non-diode laser sales organized by type. (2005 data/ 2006 forecast).

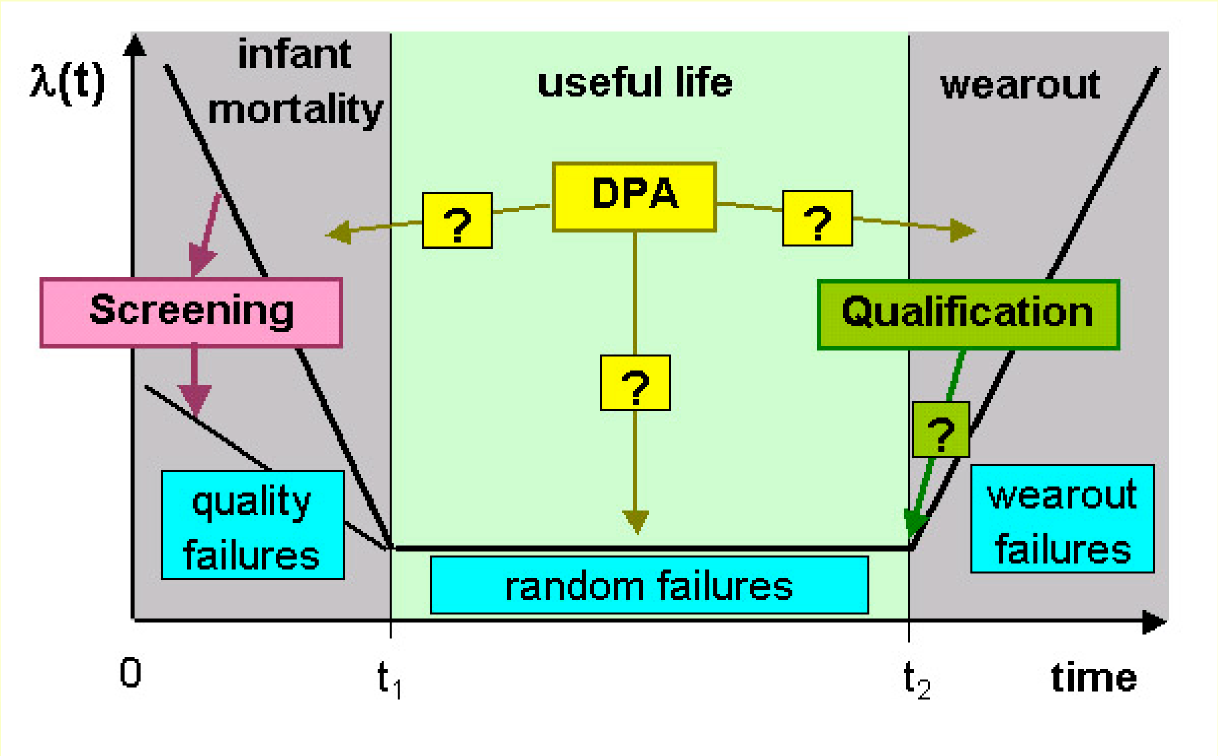
"Laser Marketplace 2006: Diode doldrums", L*aser Focus World,* February, 2006

Challenges for QCW LDAs for Space flight

GSFC

- The arrays are the power source for laser and potentially a single point failure for the instrument
- LDAs are complicated devices with multiple failure mechanisms so predicting reliability is difficult
- QCW operation causes heating with every current pulse which puts repeated thermo-mechanical strain on device
- QCW market does not support the statistically verified reliability testing found in the telecom market.
- QCW LDAs are used in a many applications with different operational parameters which further fractures the QCW market
- Statistics are expensive because of the cost of the arrays
- Vendor designs, procedures, and tests change often in an effort to improve package design which can degrade (or negate) the statistics you gather on previous devices
- It is a competitive business so vendors can come and go

"Bath Tub" Curve



Lifespan and Product Assurance System, from *PEM-INST-001: Instructions for Plastic Encapsulated Microcircuit (PEM) Selection, Screening, and Qualification*, Dr. A. Teverovsky and Dr. K. Sahu, 2003.

- This curve shows the life cycle of a set of devices
- The best "Bath Tub" has a steep initial slope, a bottom near zero, and large value of t_2-t_1
- 808 nm QCW LDAs are generally in the Infant mortality (negative slope) phase of this life cycle
- Not enough data has been taken to draw this kind of curve for QCW LDAs. (i.e. - we haven't tested to t_1)
- This means failures are difficult to predict, not that there are necessarily a lot of them

QUALIFICATION STRATEGY

- Be knowledgeable about vendors and products.

- Through testing, identify vendors with quality products and with feedback establish a mutually beneficial working relationship.

- It is important to communicate with vendors about your needs and use their expertise.

- Establish a baseline for device reliability and characterize the effects operating conditions and environment have on reliability.

- Design missions around known parameters and use architectures that will mitigate risk. (includes de-rating devices and using adequate redundancy.)

- To build the flight instrument hardware, buy extra devices and perform lifetests. In order for this testing to be significant, the testing must be done on a statistical sample of the parts you will launch.

- The tests should be as close to the actual in-flight conditions as practicable.

High-Power Laser Diode Arrays

Mark Stephen, NASA GSFC, Code 554, mark.a.stephen@nasa.gov

GSFC

Objectives

- Quantify effect of operational and environmental parameters on Laser Diode Array (LDA) performance.
- Develop procedures for purchasing, handling, storage, testing and operation.
- Develop prediction/screening capability.
- *Enable improved reliability and performance of future laser missions.*

Diagnostic, Test Capabilities & Accomplishments

Optical power measurements
- Average
- Spatially resolved
- Polarization resolved
- Temporally resolved

Electrical parameters
- Voltage
- Current
- Efficiency

Thermal Profiling
- Temporally, spatially resolved surface imaging
- Thermal modeling

Spectral Measurements
- Spatially, temporally Averaged
- Time-resolved spectroscopy
- Spatially resolved spectroscopy

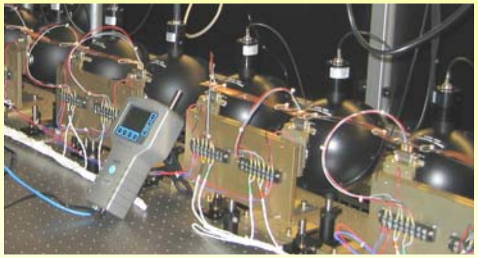
Facet Microscopy
- Near, dark field
- Extended focal imaging
- Side view
- SEM

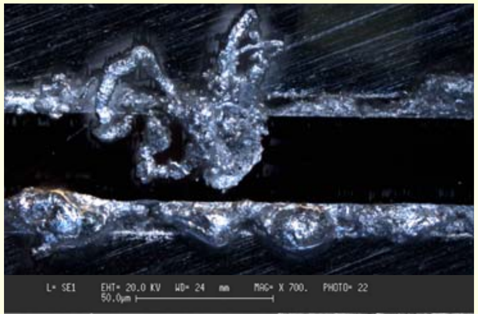
Long duration performance testing
- Laminar flow environment
- Vacuum operation

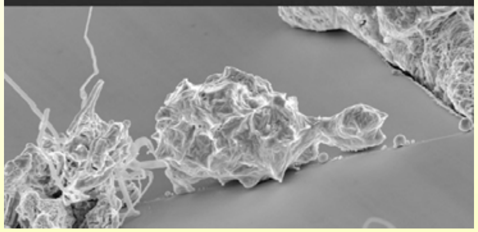
Space qualification
- Radiation
- Vibration

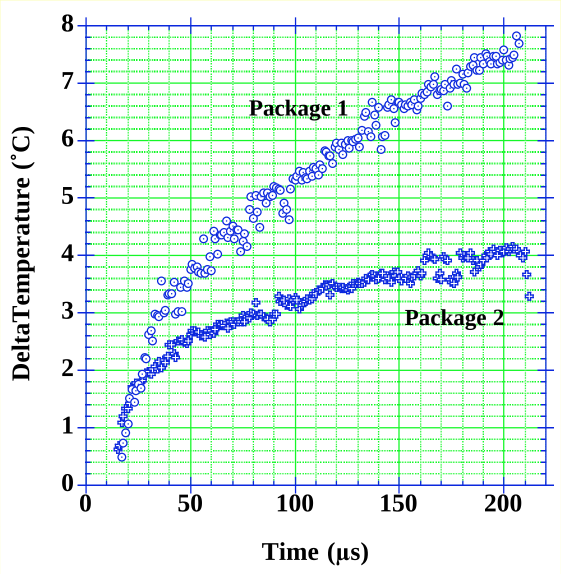
Destructive Physical Analysis

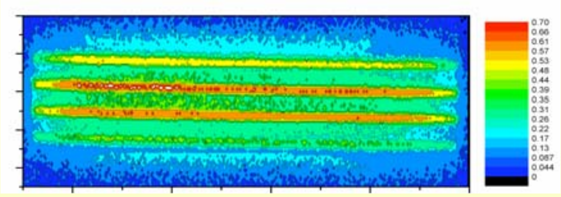
Developing Measurement
- Micro-Photoluminescence Spectroscopy

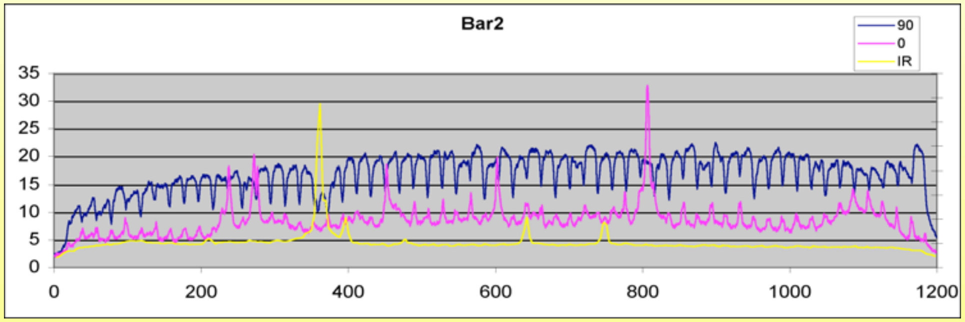




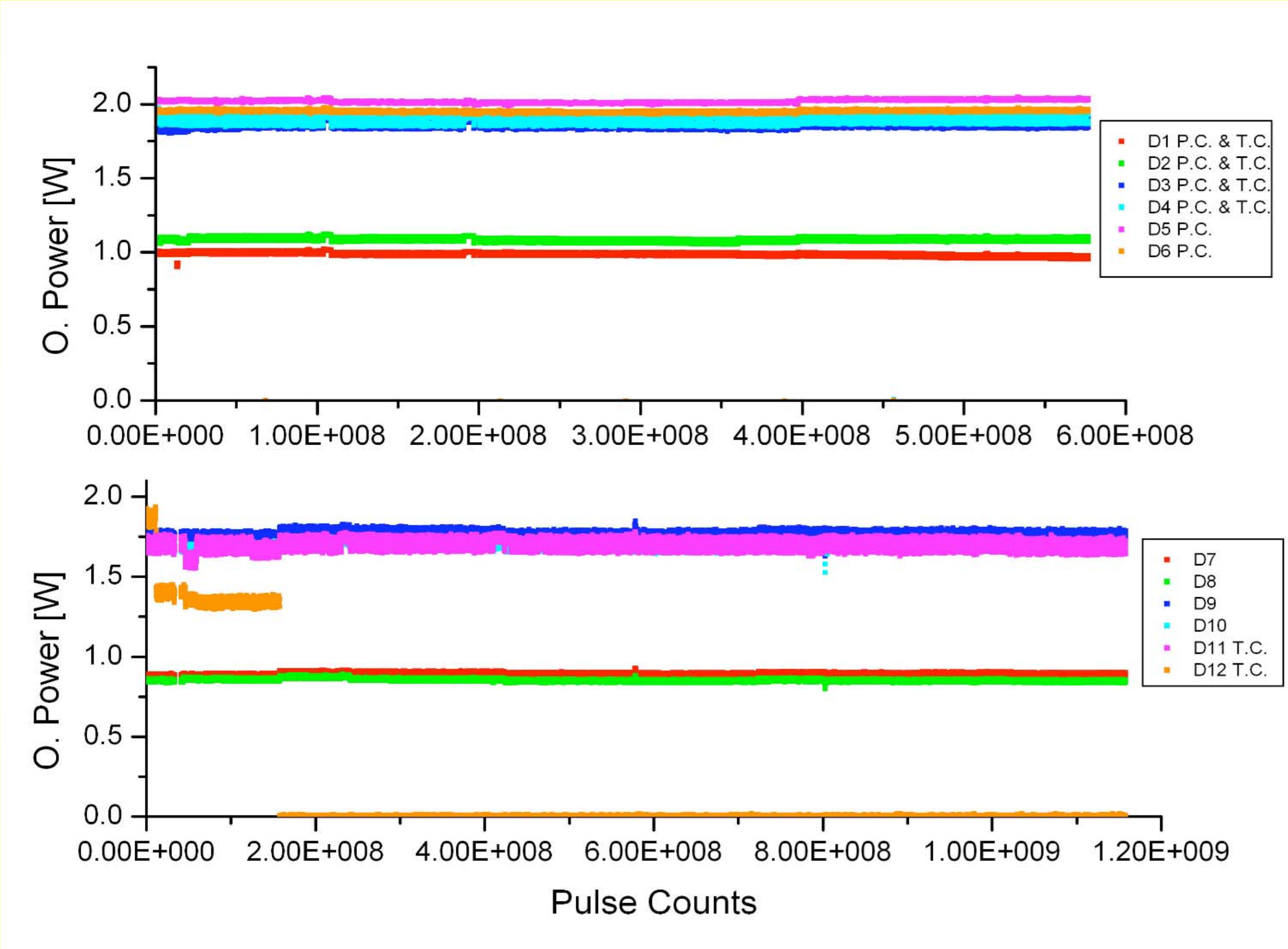






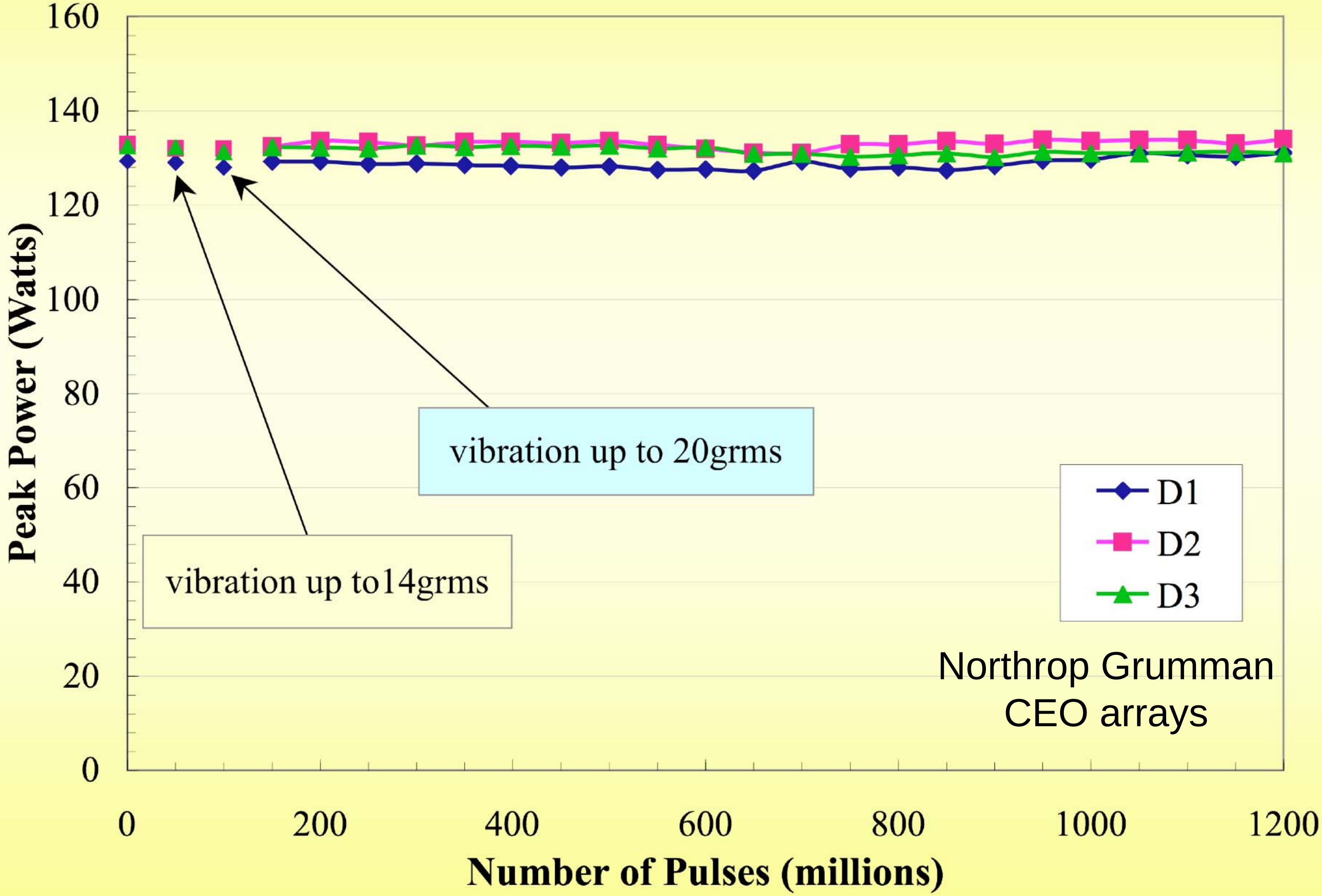


Optical Power vs. Pulse Count

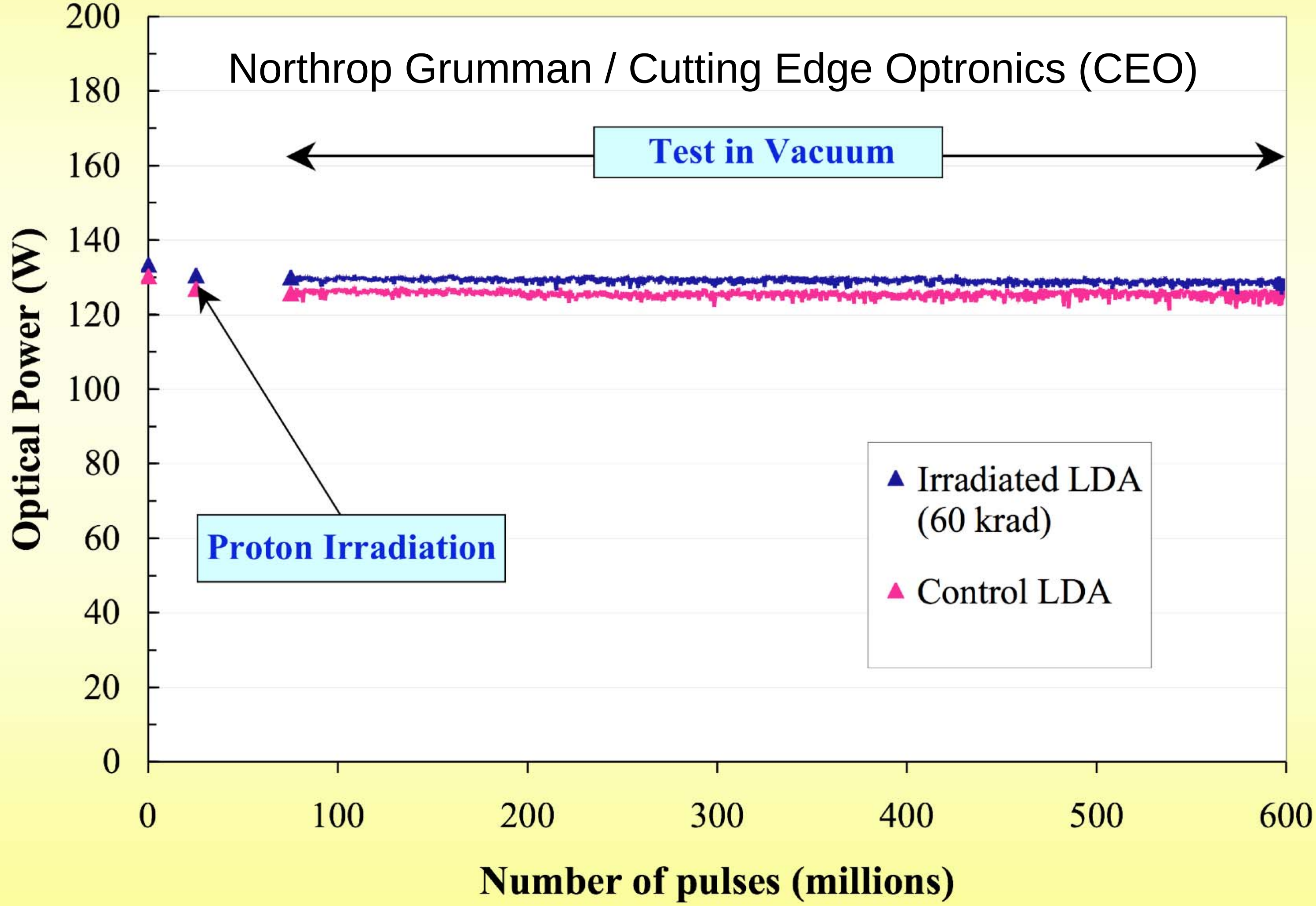


Mercury Laser Altimeter (MLA) era arrays under power and temperature cycling

Extended Operation of Vibrated Arrays

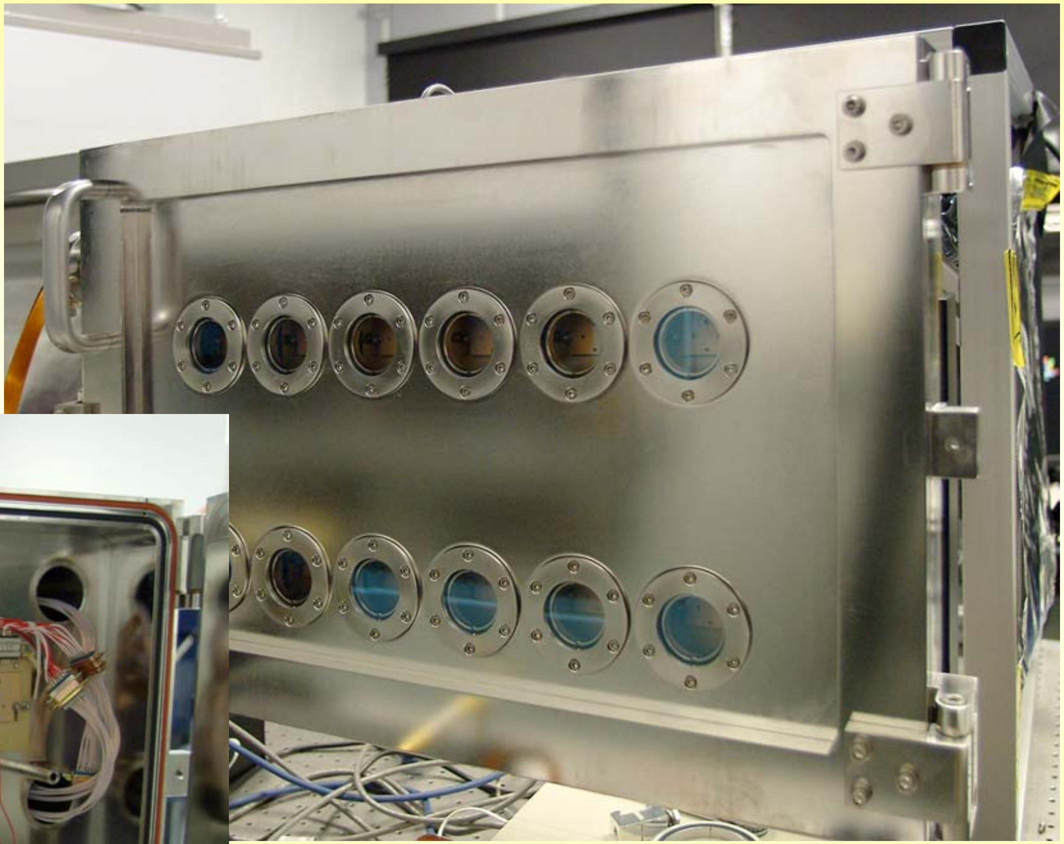


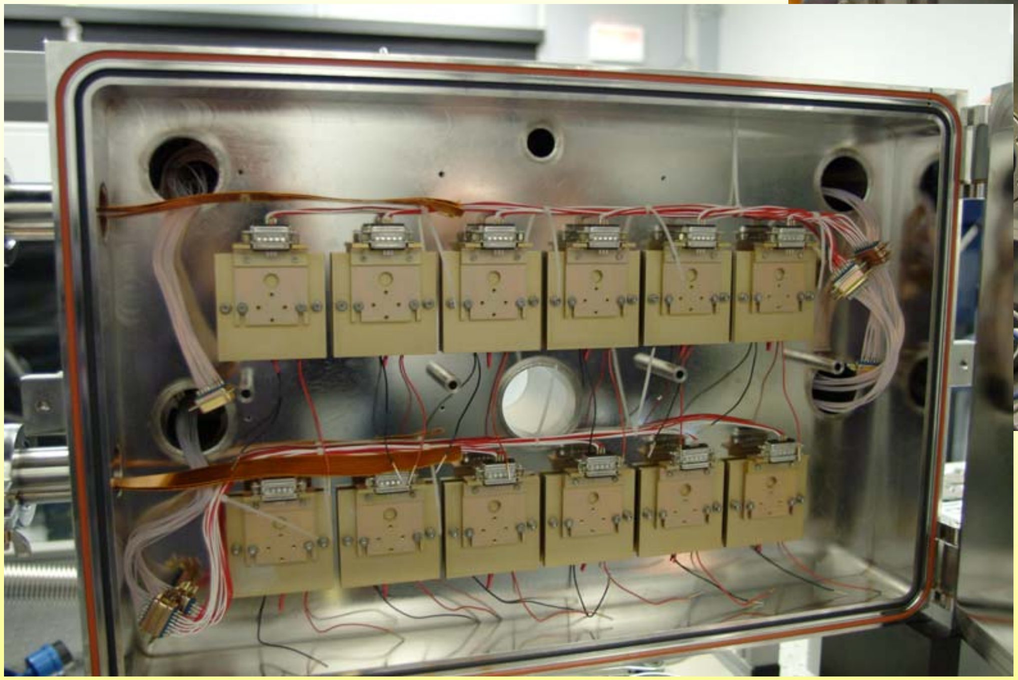
Vacuum Results



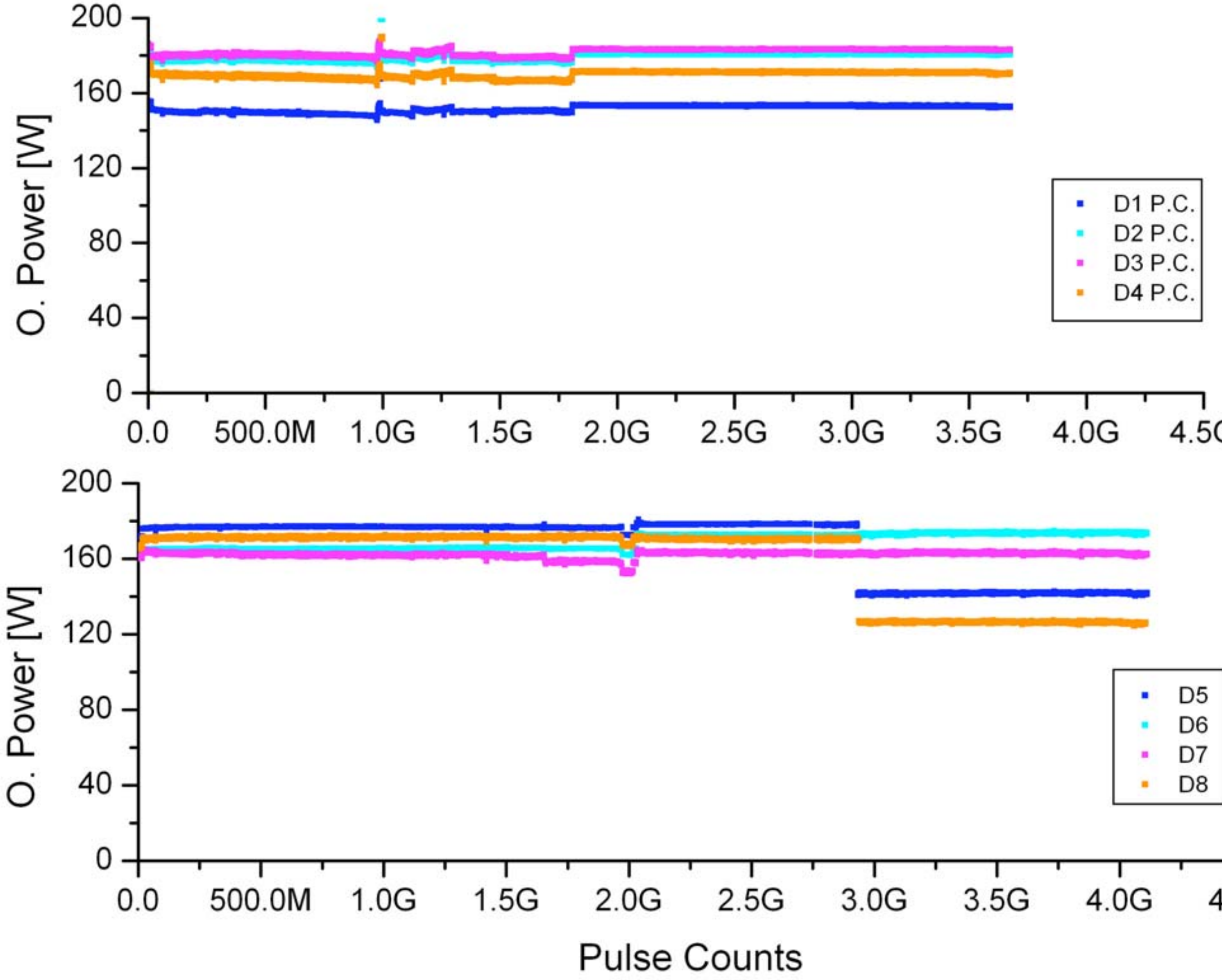
Custom Vacuum Chamber

Custom vacuum chamber with 12 LDA test positions with windows for continuous inspection





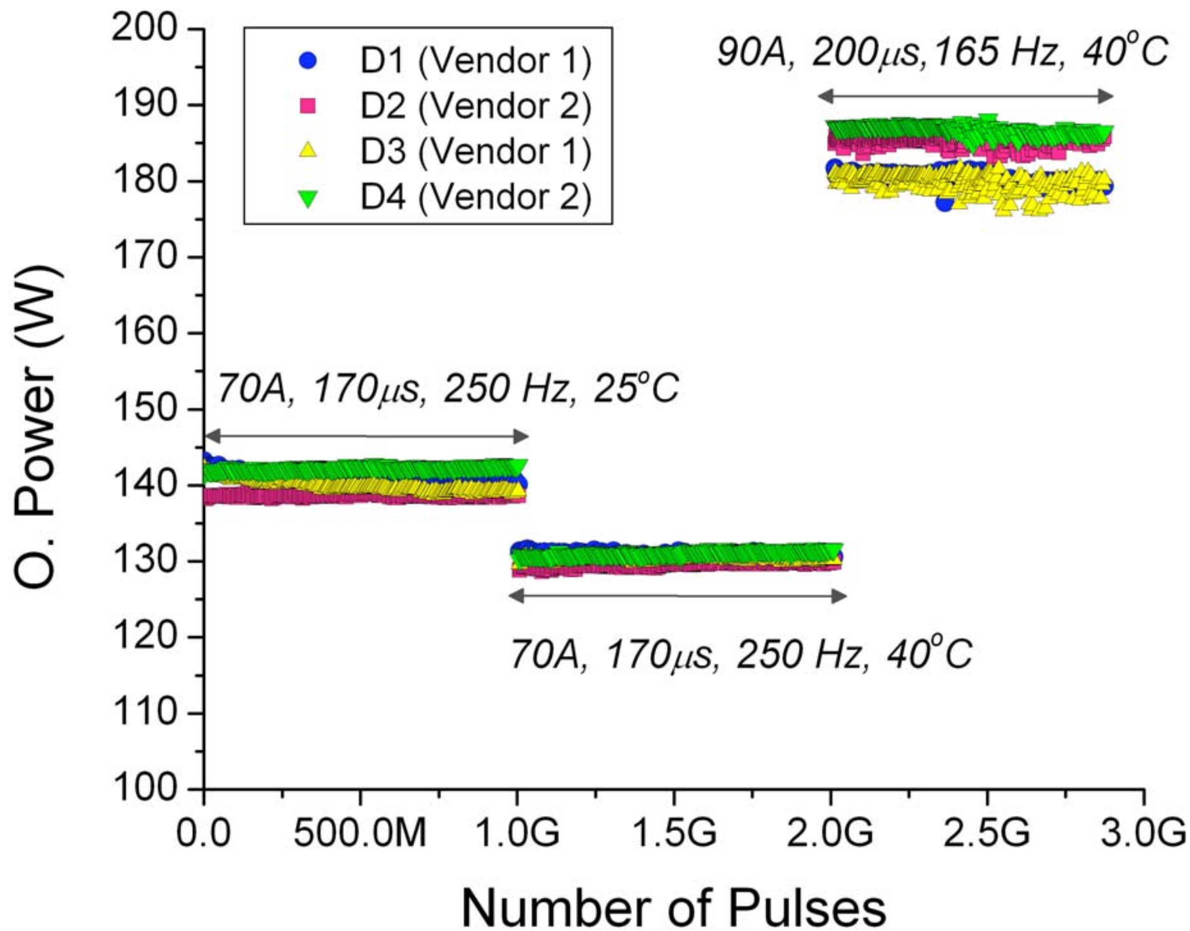
BioMM Test:
(CEO Arrays)



- Operating Conditions: I = 50 A, PW = 80 µs, f = 242 Hz, T= 25 °C.
- All LDAs have accumulated more than 3.6 billion pulses.
- 4 G-4 LDAs (top) are power cycled: ON cycle is 18 min.; OFF cycle is 2 min. [>14,000 cycles].
- 4 G-4 LDAs (bottom) are at constant power.
- Fluctuations in curves are due to test electronics and not indicative of changes in LDAs.
- Power drops in CW graph near 2.9 Billion pulses indicate bar failure.

LOLA EM Test

(Nuvonyx & Coherent Arrays)



This is an ongoing, accelerated performance test of 4 LDAs (G2 packages) to qualify two vendors, observe potential problems and compare performance to assist choosing the flight vendor for LOLA mission.

Calculated MTTF - >4 Billion

Characterized Arrays

VENDOR	TYPE	NUMBER OF LDA	NUMBER OF BARS
SDL	G 11	6	66
	G 16	5	80
	total	*11*	*146*
CEO	G 2	14	28
	G 4	37	148
	G 6	9	54
	G 11	5	55
	G 18	10	180
	total	*75*	*465*
Coherent Inc.	G 2	20	40
	G 4	8	32
	G 6	2	12
	G 16	2	32
	total	*32*	*116*
Nuvonyx	G 2	5	10
	G 4	5	20
	G 11	5	55
	total	*15*	*85*
TOTAL		**133**	**812**

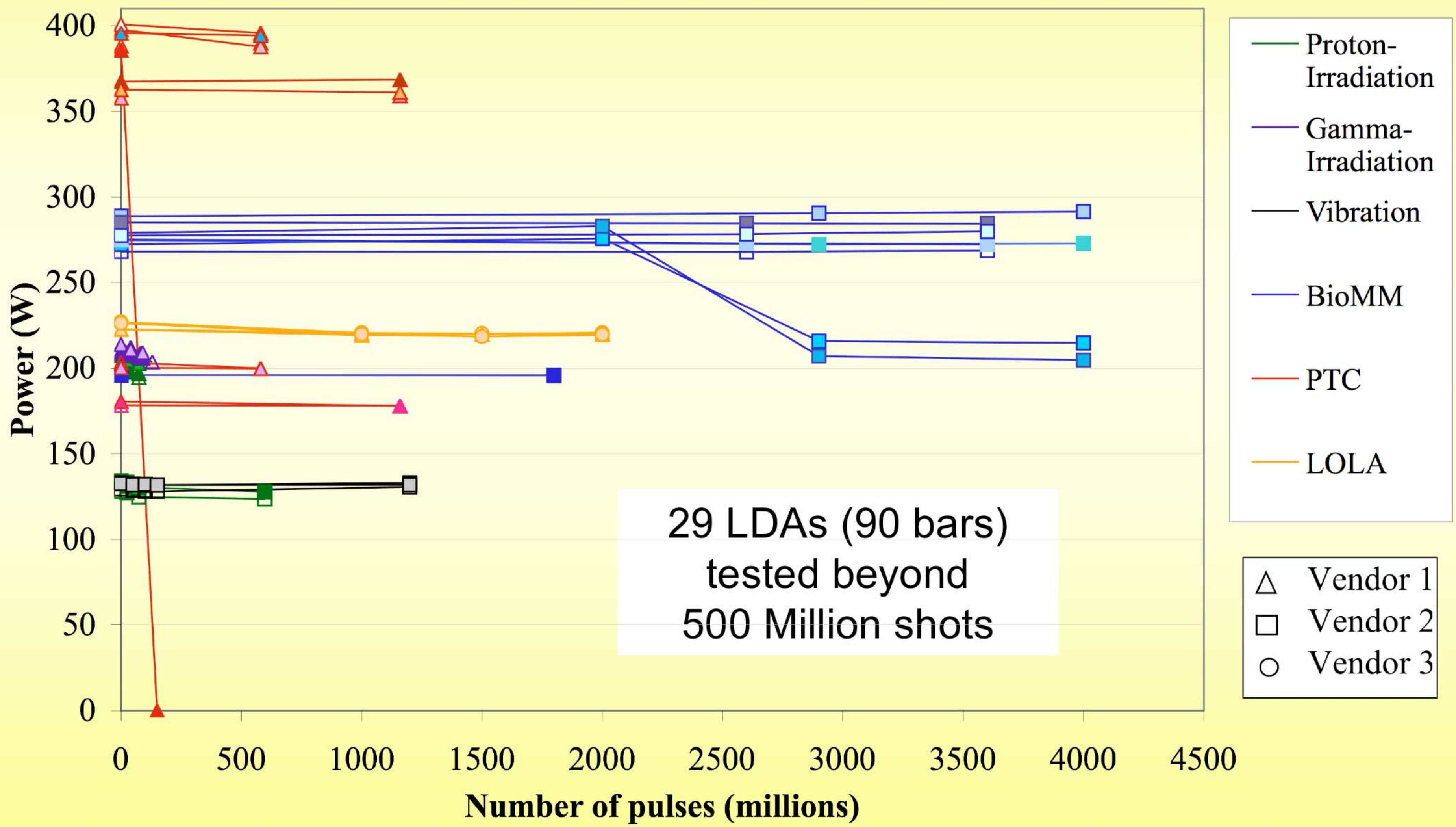
Uncharacterized

Decade	G 2	5	10
	G 4	2	8
	total	*7*	*18*
Lasertel	G 2	5	10
	G 4	2	8
	total	*7*	*18*

Type	Total number of LDA
G2	39
G4	50
G6	11
G11	16
G16	7
G18	10

TOTALS PER VENDOR	
SDL	11
CEO	75
Coherent	32
Nuvonyx	15

Summary of Extended Testing During Program



29 LDAs (90 bars) tested beyond 500 Million shots

Lunar Orbiter Laser Altimeter (LOLA) LDA Test Protocol

- Buy flight laser diode arrays (LDA) – 2 vendors x 30 arrays / vendor = 60 arrays
  - 4 arrays/vendor for flight laser assembly
  - 4 arrays/vendor for flight spare laser assembly
  - 7 arrays/vendor as build spares
  - 15 arrays/vendor for test and qualification
- Characterize all arrays
- Randomly select arrays for tests – a total of 15/vendor set aside for testing – 10 (+3 spare) for initial performance tests, 1(+1 spare) for DPA
- Do a destructive physical analysis (DPA) of one array from each vendor. If potential problems are observed, a second array can be analyzed.
- Set up and run 24/7 automated tests.
- Analyze data – Weibull (statistics) analysis, materials, failure, correlate characterization and performance data
- Using data – choose flight vendor and select arrays to be used in laser assembly and which to use for spares.
- Report on findings of tests at time of flight array delivery.
- Continue performance tests which will continue to improve statistics and knowledge base

LOLA performance test matrix

Environment	Operating Conditions: Pulse width - 170 us	Peak power rating	Vendor 1	Vendor 2
Vacuum	Nominal – 28 Hz, 70 A	70 %	2	2
	Accelerated – 250 Hz, 70 A	70 %	4	4
Air	Accelerated – 250 Hz, 70 A	70 %	2	2
	Full Rating – 175 Hz, 100 A	0 %	2	2

Advantages of Testing Approach

- LDAs qualified concurrently with LOLA flight laser integration w/ spares
- Spare vendor to mitigate risk due to poor manufacture
- Accelerated tests that will achieve the full mission goal (in pulse count) prior to laser integration
- LDAs tested in flight-like environment and operating conditions
- Analysis correlating arrays at nominal frequency with accelerated frequency.
- Material and mechanical analysis of package
- Cost effective

Summary and Conclusions

- 980 and 940 nm CW diode pumps have many advantages for space use if their use is consistent with the laser technology required.
- 808 nm QCW laser diode arrays can be integrated into space missions if they are properly tested and the laser design has adequate margin.

- Extended operation tests
  - Power/Temperature cycling (MLA) test - 1.15 billion pulses
  - Finished vacuum/radiation test - 600 million pulses
  - Finished vibration test - 1.2 billion pulses
  - LOLA engineering model LDA test - 2.5 billion pulses
  - BioMM test continues - ~4 Billion pulses, >14,000 power cycles

- LOLA testing beginning this summer